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New Applications of Gamma Spectroscopy: Characterization Tools for D&D Process Development, Inventory Reduction Planning & Shipping, Safety Analysis & Facility Management During the Heavy Element Facility Risk Reduction Program

Heavy Element Facility B251

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ABSTRACT

Novel applications of gamma ray spectroscopy for D&D process development, inventory reduction, safety analysis and facility management are discussed in this paper. These applications of gamma spectroscopy were developed and implemented during the Risk Reduction Program (RPP) to successfully downgrade the Heavy Element Facility (B251) at Lawrence Livermore National Laboratory (LLNL) from a Category II Nuclear Facility to a Radiological Facility. Non-destructive assay in general, gamma spectroscopy in particular, were found to be important tools in project management, work planning, and work control ("*Expect the unexpected and confirm the expected"*), minimizing worker dose, and resulted in significant safety improvements and operational efficiencies. Inventory reduction activities utilized gamma spectroscopy to identify and confirm isotopics of legacy inventory, ingrowth of daughter products and the presence of process impurities; quantify inventory; prioritize work activities for project management; and to supply information to satisfy shipper/receiver documentation requirements. D&D activities utilize *in-situ* gamma spectroscopy to identify and confirm isotopics of legacy contamination; quantify contamination levels and monitor the progress of decontamination efforts; and determine the point of diminishing returns in decontaminating enclosures and glove boxes containing high specific activity isotopes such as ^{244}Cm and ^{238}Pu. *In-situ* gamma spectroscopy provided quantitative comparisons of several decontamination techniques (e.g. TLC-free Stripcoat^{TM}, Radiac^{TM} wash, acid wash, scrubbing) and was used as a part of an iterative process to determine the appropriate level of decontamination and optimal cost to benefit ratio. Facility management followed a formal, rigorous process utilizing an independent, state certified, peer-reviewed gamma spectroscopy program, in conjunction with other characterization techniques, process knowledge, and historical records, to provide information for work planning, work prioritization, work control, and safety analyses (e.g. development of hold points, stop work points); and resulted in B251 successfully achieving Radiological status on schedule. Gamma spectroscopy helped to define operational approaches to achieve radiation exposure ALARA, e.g. hold points, appropriate engineering controls, PPE, workstations, and time/distance/shielding in the development of ALARA plans. These applications of gamma spectroscopy can be used to improve similar activities at other facilities.

INTRODUCTION

The Risk Reduction Program successfully downgraded the LLNL Heavy Element Facility (B251) from a Category II Nuclear Facility to a Radiological Facility. Leading up to this major achievement were significant safety accomplishments, completing objectives on time and on budget, achieving the November 2003 Milestone for reducing Inventory to 20% of the initial inventory, and reducing Inventory to < 0.03 ^{241}Am-equivalent curies by the April 2005 Milestone. Gamma spectroscopy was a key factor in this success. Novel applications of gamma ray spectroscopy were utilized for D&D process development, inventory reduction, safety analysis, and facility management.

Figure 1. The LLNL Heavy Element Facility

[1] For referral to the appropriate author, contact to whom questions should be addressed.

RRP Philosophy in Schedule Paradigm

B251's success resulted from a guiding philosophy that carefully balanced key factors:

- Decontamination cost for D&D activities (LLW vs. TRU);
- Repackaging cost for inventory activities;
- Waste disposal cost (LLW vs. TRU);
- Dose exposure during decontamination for D&D activities;
- Dose exposure during handling/repackaging for inventory activities; and
- Schedule.

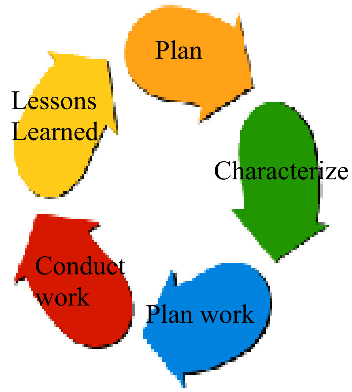
In a schedule driven paradigm, first determine *"How clean is clean enough?"* This is especially important when there are significant uncertainties concerning inventory or contamination. At the beginning of a D&D project, it is important to establish attainable goals for decontamination, determine stopping point for decontamination (diminishing returns), and when to instead explore alternative options (shipping or waste disposal).

RRP Characterization Approaches

The guiding motto of the Risk Reduction Program (RRP) was to "*Expect the unexpected and confirm the expected.*" The RRP utilized a variety of characterization tools, including: Gamma spectroscopy; Radiography; Alpha/Beta/Gamma (α/β/γ) measurements; Neutron measurements; Entry and concurrent radiation (during job) surveys; Pre-job, post-job, and concurrent contamination surveys. This selection of characterization tools resulted from lessons learned over the course of the program.

Gamma spectroscopy was pivotal in the RRP's work planning. The RRP utilized a continuous batch process, where the current activity was conducted while planning the next activity. These activities involved coordinating multiple organizations. The overall order of operations was as follows:

1. Plan the work, prepare the work plan, facilitate safety and regulatory reviews, and obtain approval to do work.
2. Characterize the material (e.g. inventory item or contaminated equipment).
3. Plan the work using characterization results.
4. Conduct the work.
    a. Repackage and stage the material, and obtain appropriate documentation.
    b. Plan the shipment, develop shipper/ receiver agreement, facilitate shipment.
    c. Ship in batches.
5. Conduct a Lessons Learned to facilitate improvements for the next batch.



Gamma Spectroscopy Improves Safety

Following the guiding philosophy of "*Expect the unexpected and confirm the expected*", B251 developed a unique work control process that increased operational efficiency and safety. The two-step work control process (ALARA review/dose prediction) utilized gamma spectroscopy for ALARA and operational efficiency. First, RRP staff reviewed historical and process records to better understand the material in question (inventory item or contaminated equipment). Particular attention was paid to sister isotopes, process impurities, and daughter products, which often weren't considered by the original researchers working with the materials. This information provided the input to the 1st ALARA Review, which estimated conservative doses and planned the initial characterization. The RRP conducted the work with survey measurements and hold points from the ALARA review. Second, RRP staff characterized the material in question and compared the results with historical and process records. This information provided the input to the 2nd ALARA Review, which used characterization results as input to dose calculation codes (e.g. Microshield) for developing more accurate dose estimates and planning the hands-on work. RRP conducted hands-on work (e.g. repackaging, neutralization/solidification, special form encapsulation, decontamination). Finally, the parcel was assayed for shipper/receiver documentation (for reuse in other programs or as waste).

As a result of the two-step work control process, the RRP maintained an excellent safety record. There were no major contamination incidents, no radiation over-exposures (in fact, doses were far lower than dose predictions), and no major injuries. Individual and collective doses were maintained ALARA.

Gamma Spectroscopy was a key factor in B251's work control processes. There was little experience in the DOE complex in decontaminating facilities with this level and variety of high specific activity, alpha emitting isotopes (e.g. ^{244}Cm, ^{238}Pu). The success of B251 work control processes was demonstrated by the excellent safety record (Fig. 2). Collective annual whole body doses were at least three times lower than ALARA goals and more than 10 times lower than conservation dose projections. Individual annual external whole body doses were less than 150 mrem.

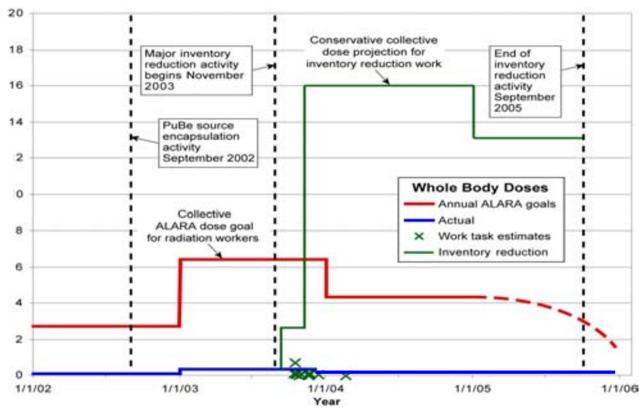
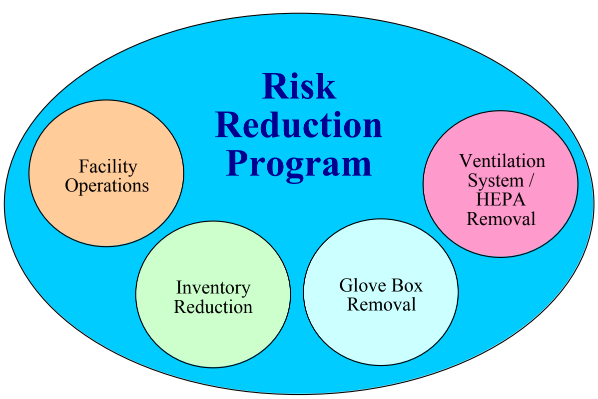


Figure 2. ALARA Comparison of Actual vs. Predicted Dose Demonstrates Success of Work Control Practices

RRP Activities Utilize Gamma Spectroscopy

The RRP was composed of facility management and three projects: Inventory Reduction, Glovebox Removal (D&D), and Ventilation System Removal.



The Inventory Reduction Project utilized gamma spectroscopy to: identify and confirm isotopics of legacy inventory, in-growth of daughter products and the presence of sister isotopes as well as process impurities; quantify inventory; prioritize work activities for project management; and supply documentation to satisfy shipper/receiver requirements.

The D&D Project utilized gamma spectroscopy both as a D&D process development tool and as characterization tool in support of D&D. *In-situ* gamma spectroscopy provided quantitative comparisons of several decontamination techniques such as TLC-free Stripcoat^{TM}, Radiac^{TM} wash, acid wash, and scrubbing. Non-destructive assay was used as a part of an iterative process to determine the appropriate level of decontamination and optimal cost to benefit ratio. D&D activities utilized *in-situ* gamma spectroscopy to: identify and confirm isotopics of legacy contamination; quantify contamination levels and monitor the progress of decontamination; and determine the point of diminishing returns in decontaminating glove boxes.

Facility Management Utilizes Gamma Spectroscopy

Facility management followed a formal, rigorous process where gamma spectroscopy and analytical chemistry was provided by an on-site independent, state certified, peer-reviewed laboratory, in conjunction with other characterization techniques, process knowledge, and historical records, to provide information for work planning, work prioritization, work control, and safety analyses (e.g. development of hold points, stop work points, and bounding hazard analysis); and resulted in B251 successfully achieving Radiological status on schedule. Gamma spectroscopy helped define operational approaches to achieve ALARA, e.g. hold points, appropriate engineering controls, PPE, workstations, and time/distance/shielding in the development of ALARA plans. These applications of gamma spectroscopy can be used to improve upon similar activities at other facilities.

De-inventorying and decontaminating a legacy facility that had not been operated for almost a decade presented unusual challenges. Some items dated back over 40 years and were stored in a variety of conditions, including underground storage vaults (USVs), Mosler safes, hot cells, and rooms in variety of engineered containers (e.g. centrifuge cones, slip-lid cans, dog bones, and USV containers). Characterization facilitated efficiently and safely packaging legacy items for reuse onsite and shipment offsite, and disposition to waste. Characterization helped the RRP reduce the number of items requiring handling and opening down to the source level, allowing simpler repackaging operations and thereby minimizing dose. Furthermore, characterization facilitated efficient repackaging of co-located items, reducing the number of repackaging steps and avoiding severe schedule implications that otherwise be required to repackage a large number of co-located items.

Self-checking Inventory Control Process

The RRP utilized a self-checking process for inventory control that followed the guiding principle of *"Expect the unexpected and confirm the expected."* Records had been kept to requirements of the times, and often did not meet modern standards; many records included cryptic hand-written entries. There was a large risk of unknown legacy items. The RRP characterized each stored inventory item and each repackaged parcel. Inventory both increased and decreased due to characterization results. The RRP created a robust system for examining process knowledge in combination with characterization (Fig. 3). This systematic approach was a fundamental key to the success of B251.

The first part of the inventory control process was to review records and conduct interviews. RRP staff reviewed hand-written process notebooks, Materials Management records, interviewed previous facility managers and numerous previous facility residents, and contacted legacy offsite suppliers. In the time since legacy items originated with offsite suppliers, numerous changes occurred at those suppliers (name changes, mergers, out-of-business, etc.). These corporate changes at legacy suppliers required investigation, i.e. many supplier records were not as easily retrieved as anticipated. The second part of the inventory control process was characterization. Characterization included: gamma spectroscopy, X-ray radiography, alpha spectroscopy, visual examination, and Alpha/Beta/Gamma ($\alpha/\beta/\gamma$) measurements.

Figure 3. Self-checking Inventory Control Process

X-ray Radiography in Hot Cell

Radiography was essential for safe and efficient inventory reduction. Used in conjunction with gamma spectroscopy, radiography was a very powerful tool in inventory reduction. Radiography helped determine the condition of unknown legacy packaging, understand shielding issues with respect to gamma spectroscopy, minimize required repackaging and dose, helped plan repackaging operations efficiently and safely, facilitated shipments, and supported shipping documentation.

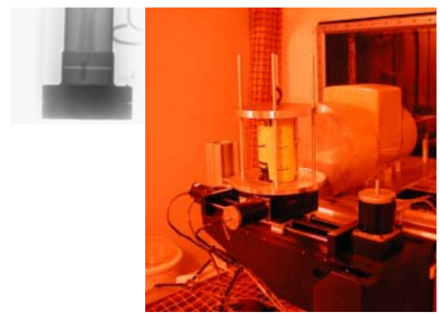


Figure 4. Radiography Increases Safety and Efficiency

Unique Gamma Spectroscopy

During the RRP, many samples containing exotic isotopes were analyzed, including highly-isotopically-pure samples of $^{238, 239, 240, 241, 242}$Pu, $^{233, 234, 235, 236, 238}$U, and isotopes of americium, curium, californium, among others. It was often said during the project that samples "ranged from A (actinium) to Z (airconium)." One particularly fascinating isotope was ^{242m}Am, a little-studied 140-year isomeric state (Fig. 5). Characterization included data reports with peer-reviewed, independent verification provided by Chemistry and Materials Science Environmental Services (CES). To reach Radiological status, CES increased their characterization throughput by factor of 20. CES conducted gamma spectroscopy on over 770 items, 72 high activity alpha-swipe samples, 66 *in situ* gamma spectroscopy scans of glove boxes, and 45 low background waste items.

Figure 5. Discussing ^{242m}Am spectra

Role of Gamma Spectroscopy in Shipping

Shipping was important to RRP's success. Key lessons learned include the need to recognize package availability and shipping constraints; develop shipper/receiver agreements (which often required a great deal of lead time and was important to tackle early in the planning process); develop clear, agreed upon expectations for known issues; schedule for waste characterization, paperwork processing, acceptance, and transportation; and be aware that a large number of parcels can swamp characterization programs and transportation. Multiple paths are important because unanticipated events can occur at receiving facilities, e.g. for mixed LLW disposition. Furthermore, it is critical to select and obtain correct containers dependent on the receiving site:

- Pipe Overpack Container (POC) for high dose items,
- Standard Waste Box (SWB) for TRU glove boxes not decontaminated to LLW,
- 10 Drum Overpack for blue cave enclosures,
- Custom Type A Containers for special contaminated enclosures (glove boxes), and
- Special Form Container for sealed sources.

In-situ Gamma Spectroscopy for D&D

In-situ gamma spectroscopy is important in determining the type and initial level of contamination, the progress of decontamination, and supporting waste documentation.

In-situ gamma spectroscopy supported D&D Process Development

The RRP monitored the progress of decontamination and compared the effectiveness of several decontamination techniques using *in-situ* gamma spectroscopy (Fig. 6 & 8). Gamma spectroscopy resulted in a groundbreaking success - no one had decontaminated facilities with this level and variety of high specific activity, alpha emitting isotopes (e.g. ^{244}Cm, ^{238}Pu, ^{228}Pa, aged ^{232}U). D&D processes developed using applications of *in-situ* gamma spectroscopy were pivotal to the success. The RRP completed D&D of 40 of 49 Enclosures in 1 year; characterized all enclosures (gamma spectroscopy, alpha-swipe tab sampling); processed 37 lower-contaminated gloveboxes through D&D and shipped to RHWM as LLW; and emptied 2 highly-contaminated Blue Cave enclosures with little or no contamination to the room. Special packaging of contaminated equipment included a glovebox transferred as Greater-than-Class-C Waste in a Standard Waste Box (SWB) and 2 glove boxes transferred as Greater-than-Class-C Waste in a Type A Box. This work generated over 800 waste parcels, 84 TRU drums, and numerous LLW drums. Radioactive contaminants included: ^{166m}Ho, ^{232}U, ^{233}U, ^{235}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, ^{242m}Am, ^{243}Am, ^{243}Cm, ^{244}Cm, ^{246}Cm, ^{248}Cm, and ^{249}Cf.

Figure 6. Conducting *in-situ* gamma spectroscopy of contaminated glove box and equipment

B251 experimental decontamination results determined that emptying removes a large fraction of activity and one or two passes of TLC-free StripCoat™ removes the bulk of loose activity. Scrubbing surface with an acidic solution loosens remainder of surface activity. Remaining material removed by another pass of TLC-free StripCoat™. Additional passes of acid wash and TLC-free StripCoat™ remove less and less residual activity because residual material remained embedded under metal surface. Using *in-situ* gamma spectroscopy clearly identifies the point of diminishing returns (Fig. 7).

Examining these experimental decontamination results in more detail, the choice of the appropriate decontamination techniques depends upon the level of contamination and type of contamination. B251 divided glove boxes by level of contamination – Tier I were those predicted to be easiest to decontaminate while Tier III were those predicted to be the most difficult to decontaminate. Tier II glove boxes were those that required *in-situ* gamma spectroscopy and swipe tab sampling to be sorted into either Tier I or Tier III. For Tier I (easiest) glove boxes and enclosures, equipment was removed and the interior was wiped with Kimwipes™ and Kay-dry's™ dampened with Radiac wash™. This was followed by application, and removal, of TLC-free StripCoat.™ This approach was found to be sufficient to meet waste removal criteria. For Tier III (most heavily contaminated) glove boxes and enclosures, equipment was removed and the same steps were taken as for Tier I. Additionally, acid washing with 10% HNO_3 followed by neutralization with sodium bicarbonate was necessary. Sometimes multiple treatments were required. A final coat of TLC-free StripCoat™ was left in place as a fixative.

Why Gloveboxes Containing High Specific Activity Isotopes are Difficult to Decontaminate to Low Level

High specific activity isotopes are very difficult to decontaminate. Tread carefully when working with these isotopes, ^{244}Cm and ^{238}Pu are very different animals from what most researchers are familiar with (Fig. 7). You should not treat them as you would weapons grade plutonium.

Isotope	Half-life (years)	Specific activity (Ci/g)	Mass of oxide powder (mg) to yield 0.01 Ci	Volume of oxide powder (cc) to yield 0.01 Ci
^{239}Pu	2.44 x 10^4	0.061	185	0.0148
^{238}Pu	86.4	17.4	0.575	0.0000522
^{241}Am	458	3.24	3.09	0.000276
^{243}Am	7.95 x 10^3	0.185	54.0	0.00491
^{244}Cm	17.6	83.3	0.120	0.0000109
^{245}Cm	9.3 x 10^3	0.157	63.7	0.00579

Figure 7. Comparison of Specific Activities for Unique Isotopes

Alpha recoil is the reason for this large difference in behavior between high specific activity isotopes and more common radionuclides.

Alpha recoil results in embedded contamination. For every alpha recoil event, about 1600 displacements of other nuclides occur within a radius of 10 to 20 nm, while the alpha particle itself causes about 100 knock-on events over a distance of 20µm. The accumulation of damage produces different effects. This results in high specific-activity, high-energy alpha-emitting radionuclides physically "driving" daughter radionuclides, and adjacent radioactive materials, into matrix of substrate material. This driving of material results in material being embedded up to approximately 20 nm deep into the substrate. Thus alpha recoil can embed radionuclides into a surface, resulting in "embedded" contamination. Removal of "embedded" material is very difficult, sometimes impossible, without physically abrading the substrate surface. In contrast, loose radioactive materials, especially particulate matter, are removed quickly and with relative ease using decontaminating agent such as TLC-free StripCoat™.

On an atom basis, decontamination to LLW requires removing ~1500 times as much for ^{244}Cm as for Weapons-Grade (WG) Pu because ^{244}Cm is 1500X as active as WG Pu. Decontamination of ^{244}Cm is difficult. With radioactive material embedded within the metal, 25 to 50 passes of TLC-free StripCoat™ and acid wash will not decontaminate some contaminated glove boxes down to LLW. In the case of a particular enclosure, the processing of ~200 Ci of ^{244}Cm by an aqueous technique has rendered this box very difficult to decontaminate.

Initial *in-situ* gamma spectroscopy indicated that the enclosure contained on order of 1.0 Ci of ^{244}Cm before decontamination. It measured approximately 0.85 Ci after the equipment, tools, apparatus, and loose items were passed out. After removing most "loose" contamination with the first of three TLC-free StripCoat™ applications, 0.47 Ci remained. Following two more TLC-free applications, one Citri-Strip™ paint remover application, and one dilute mineral acid wash (2M HNO3), another *in-situ* gamma spectroscopy measurement indicated 0.31 Ci remained. After these decontamination cycles, the glove box contamination remained approximately 4000 to 5000 nCi per gram, while the LLW limit is 100 nCi per gram.

In comparison, a more common WG Pu box with the same number of grams of WG Pu as 1.0 Ci of ^{244}Cm would be only $7*10^{-4}$ Ci of WG Pu, and could have been disposed of as LLW.

Aggressive techniques removed only small fractions of the remaining contamination, indicating that the material was intractable embedded contamination. D&D asymptotically approached 100 nCi per gram, but many more cycles of decontamination would still be required. It is highly probable that years of effort could be applied to decontaminating this glove box and it would still be TRU waste. At this point, you must consider the choice of disposal options and ALARA. Although doses per hour are reasonably low, there are questionable merits of accepting thousands of man-hours of dose to decontaminate to

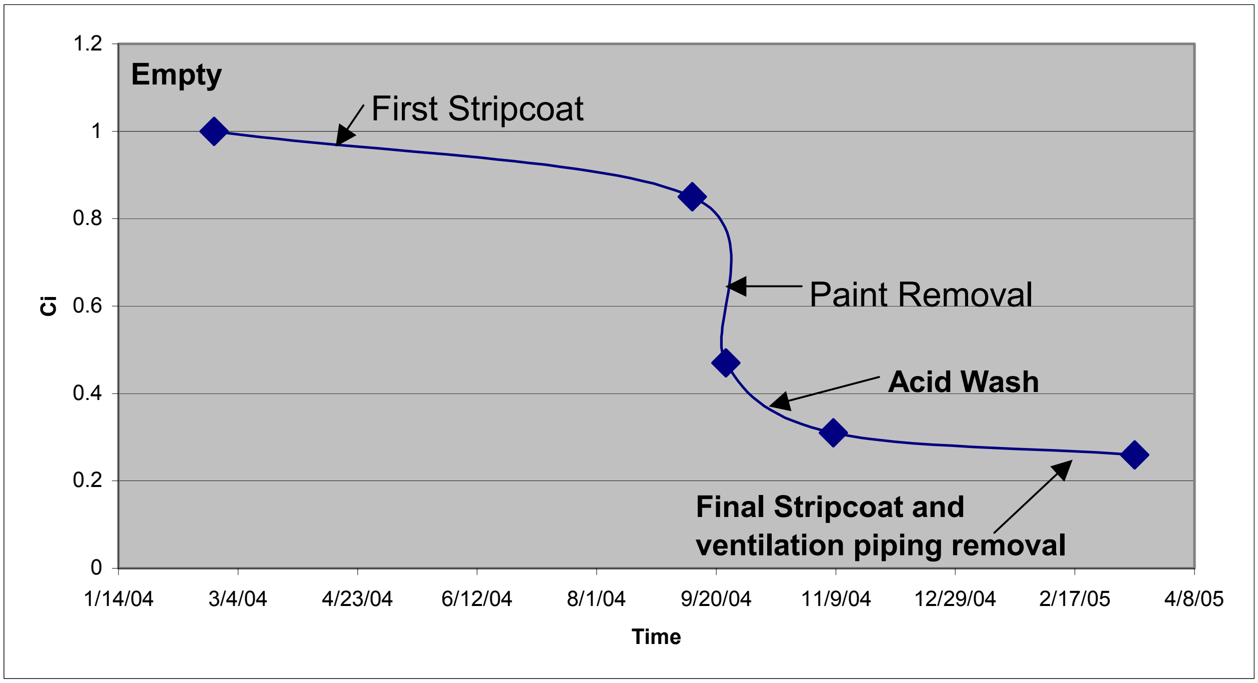


Figure 8. Progress of D&D monitored using *in-situ* gamma spectroscopy

TRU versus LLW limits, or NTS versus WIPP requirements. For example, dose at face of glove box ranges from about 20 to > 50 mRem per hour.

Repeated decontamination efforts violate ALARA principals with very little decontamination to show for effort.

Facility Management Utilizes Gamma Spectroscopy

B251 Facility Management developed robust processes for inventory control and work control. The self-checking inventory control system followed a formal, rigorous process utilizing an independent, state certified, peer-reviewed gamma spectroscopy program in conjunction with other characterization techniques (e.g. radiography, α/β/neutron measurements), process knowledge, and historical records. This provided information for:

- Work planning, work prioritization, work control and safety analyses (e.g. development of stop work points and bounding hazard analysis);
- Helps define operational approaches to achieve ALARA, e.g. hold points, appropriate engineering controls, PPE, workstations, and time/distance/shielding.

In a legacy facility, it is critical to develop robust processes that can handle surprises from legacy unknowns. B251's inventory control and work control processes resulted in significant safety improvements and operational efficiencies.
As a result of robust processes and application of lessons learned, B251 successfully completed a Facility Startup Readiness Assessment (RA) [with NNSA] as well as three operational RAs [institutional with NNSA oversight].

Gamma Spectroscopy & Work Control

B251 utilized a "building block" work plan process. Such a process provides flexibility, ease of use, and is best suited for situations where performing the same operation may result in drastically different dose rates from item to item. Once the initial effort to write the procedures is complete, creating a work plan is relatively simple in comparison to other facility's work control process.

The following discussion describes how the "building block" work plan process functions. A project leader identifies what needs to be done and determines how they would like to perform that activity. The overall order of the process is as follows:

1. Assemble procedures for an overall activity from a selection of previously approved procedures for specific operations that make up that activity. For example, to repackage an item in a glove box, select procedures for checking infrastructure functionality (e.g. room ventilation, glove box ventilation, continuous air monitors), entering specific locations and retrieving items, and open air transfers into and out of a glove box.

2. “Plug in” results from Characterization (e.g. gamma spectroscopy) about the specific items in question.
3. Condcut a standing meeting with reviewers to assess the proposed work package. Reviewers may include: ES&H safety disciplines (e.g. health physics, industrial hygiene, industrial safety, fire protection, environmental analysts), safety analysts (USQ), facility engineering (Configuration Management), and facility management. The reviewers assess and assimilate the reviewers comments and develop a completed, *final* work package.

This approach minimizes review time as reviewers already understand each operation and focus their assessment on the integrated activity and specific hazards. This approach allows reviewers to assess each inventory item individually, which is important when radiation levels may vary greatly for the same operation depending on isotope (e.g. from a few mRem/hr to 5 Rem/hr). Thus ALARA controls may vary between items, and these details are discussed in pre-start meetings.

Additionally, the “building block” work plan process provides operational flexibility so you don’t have to stop work to re-enter paperwork processes. The project leader and reviewers consider possible issues and builds in contingency plans and previously approved procedures (e.g. glove changes, filter changes, spill plans). They expect the unexpected, and take steps to find surprises when conducting the work, such as by monitoring for both neutrons and $\alpha/\beta/\gamma$ and establishing hold points for radiation levels and contamination. These hold points are based upon input from characterization (e.g. gamma spectroscopy) that helps the project leader to better understand the work environment.

When using gamma spectroscopy to support work control, it is important to assume conservative, bounding values for legacy inventory. Given constraints of gamma spectroscopy, do not assume precise value to the last significant digit (e.g., conservatively assume 20 Ci instead of 11.1 Ci).

Conclusions

The B251 Risk Reduction Program was a success! During the program, key lessons were learned. The novel applications of gamma spectroscopy developed during the program can improve upon similar activities at other facilities. Key to this success is the RRP philosophy in a schedule driven paradigm.

- *“Expect the unexpected and confirm the expected”*
- Recognize when you reach the point of diminishing returns,
- Develop robust processes that anticipate and can handle surprises,
- Plan, plan, and re-plan *“Measure twice, cut once”*

Robust processes utilizing gamma spectroscopy significantly improved safety and contributed to the RRP’s success by supporting:

- Inventory Reduction,
- D&D process development,
- D&D activities, and
- Facility Management (Work Planning, Work Control, ALARA, and Safety Analyses).

Key Contributors to B251’s Success

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NOTE: Figures 8 – 12 are located on subsequent pages.

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Staff from multiple organizations played significant roles in downgrading B251 from Nuclear Category 2 to Radiological

Impressive safety accomplishment
No one had decontaminated facilities with this level and variety of high specific activity isotopes (e.g. ^{244}Cm, ^{238}Pu)
Dramatic cost savings, \$250 million under current regulations

Figure 8. B251 – impressive success!

Gamma Spectroscopy in Inventory Reduction

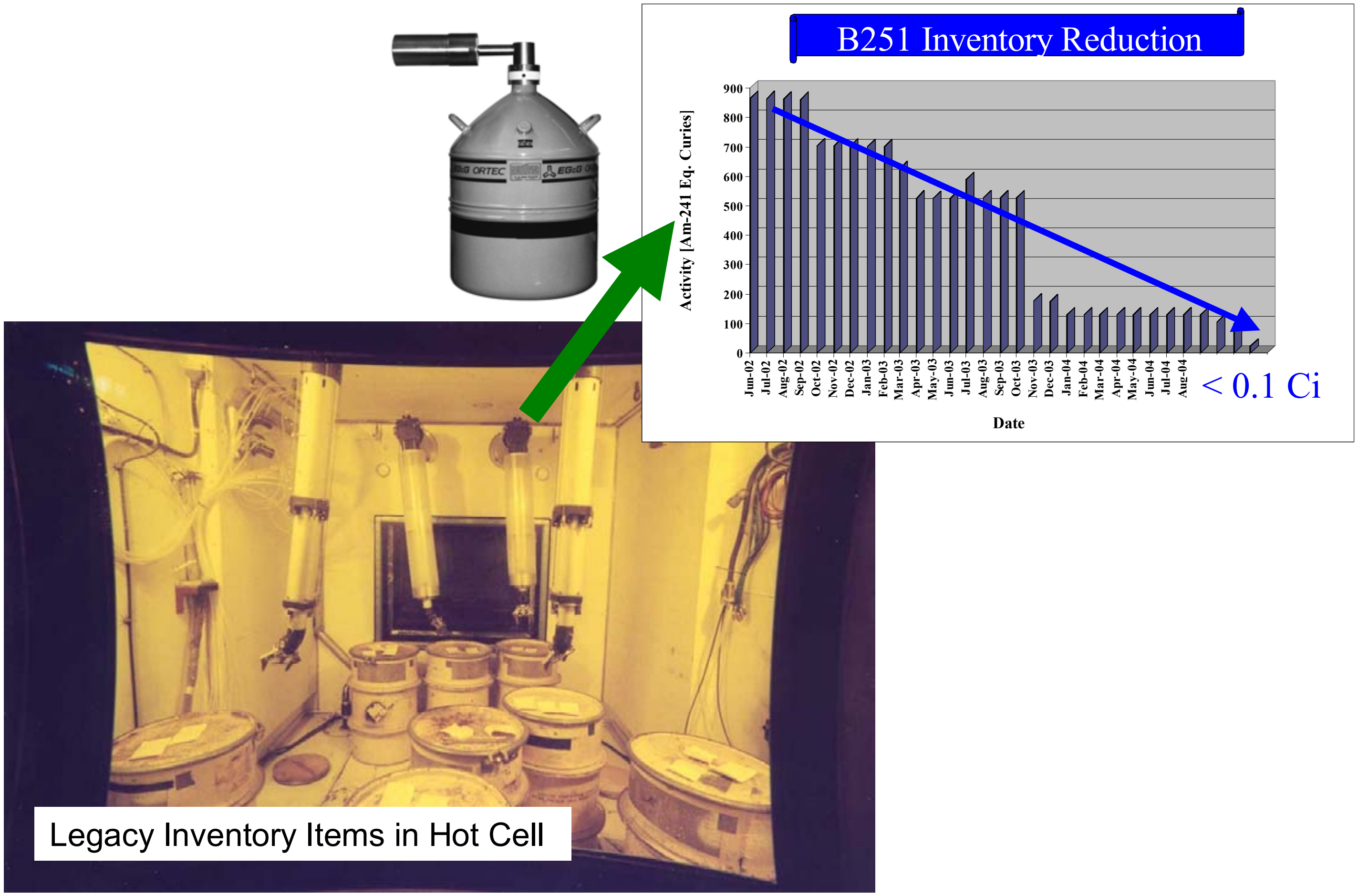


Figure 9. B251 Before and After Inventory Reduction Activities

Preparing, emptying, decontaminating, disconnecting, packaging, characterizing, and shipping enclosures

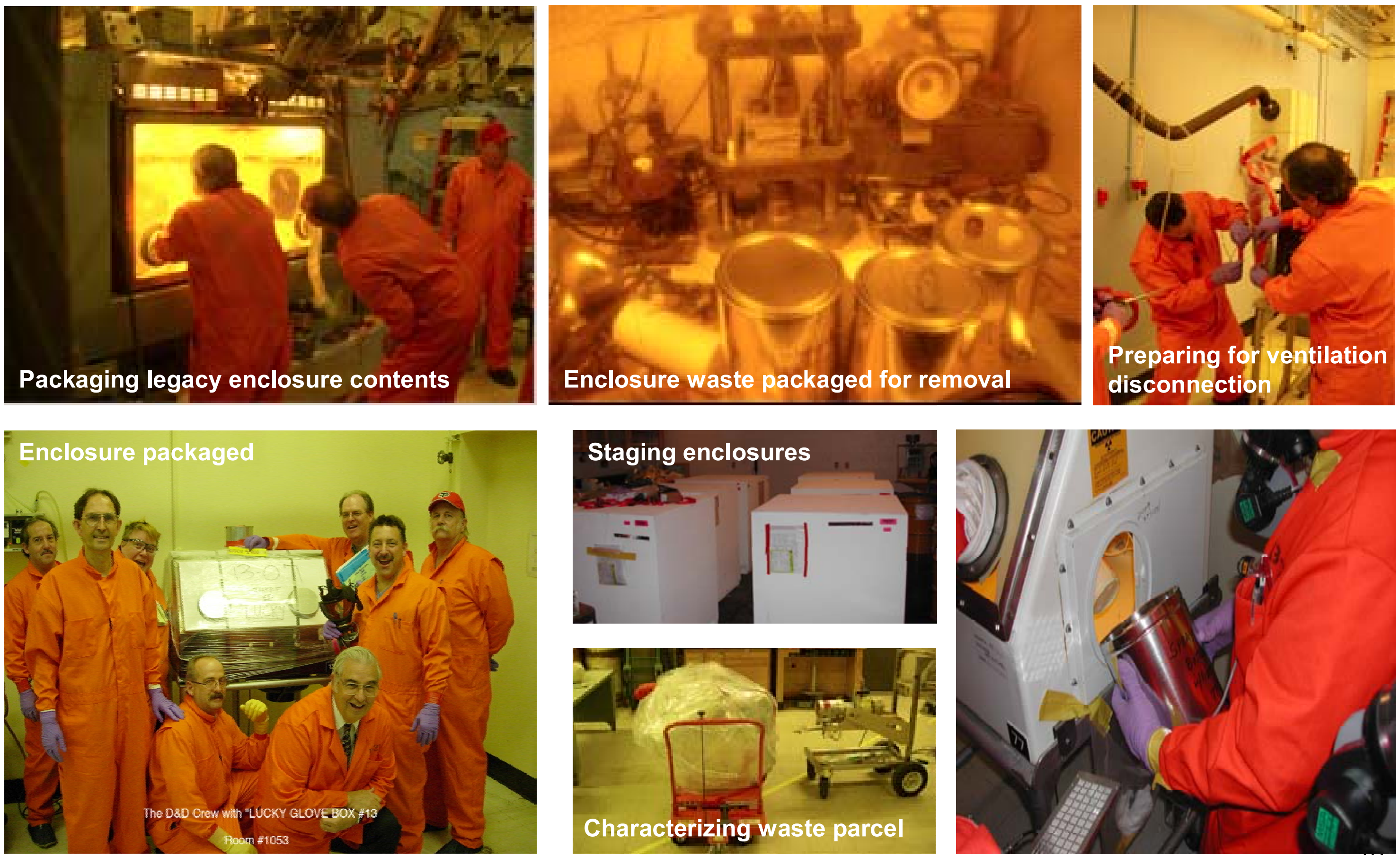


Figure 10. Examples of D&D Activities

Enclosure D&D: Conditions of Legacy Equipment

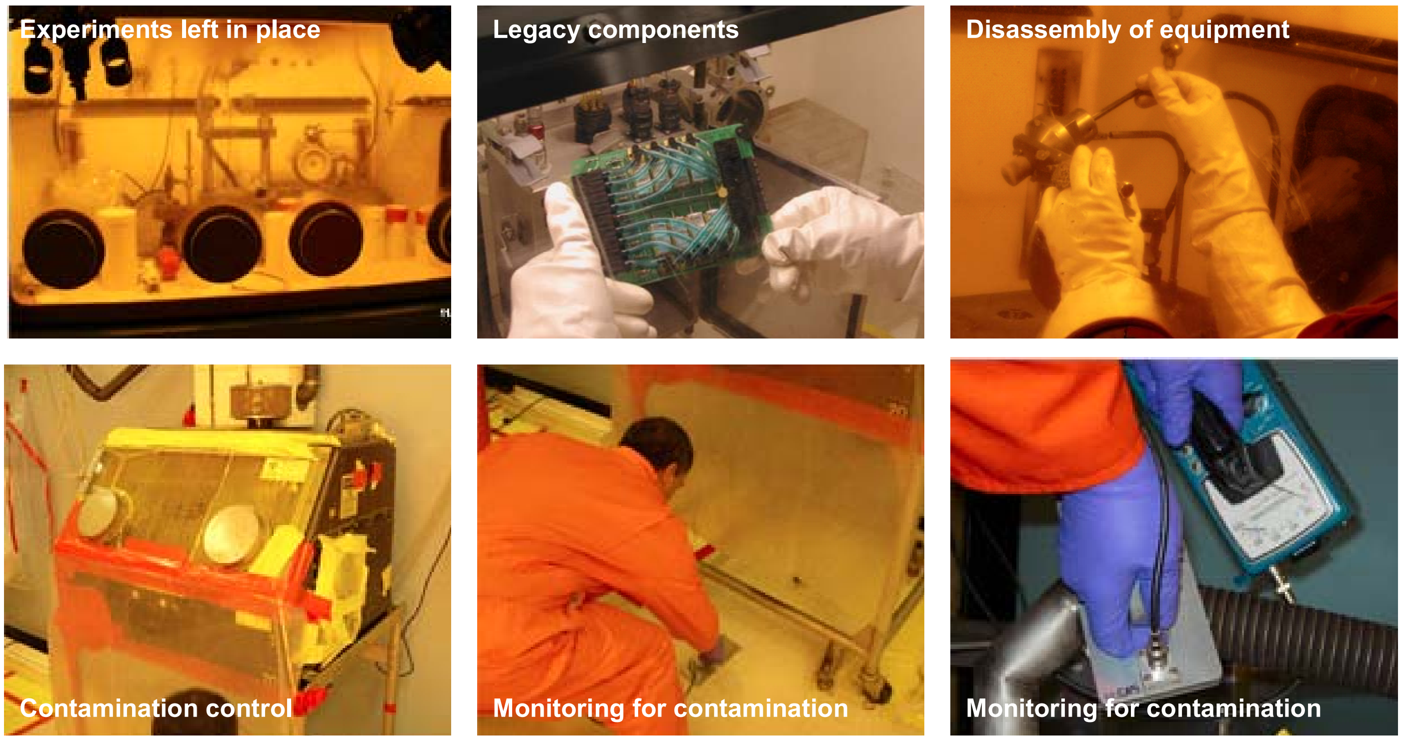
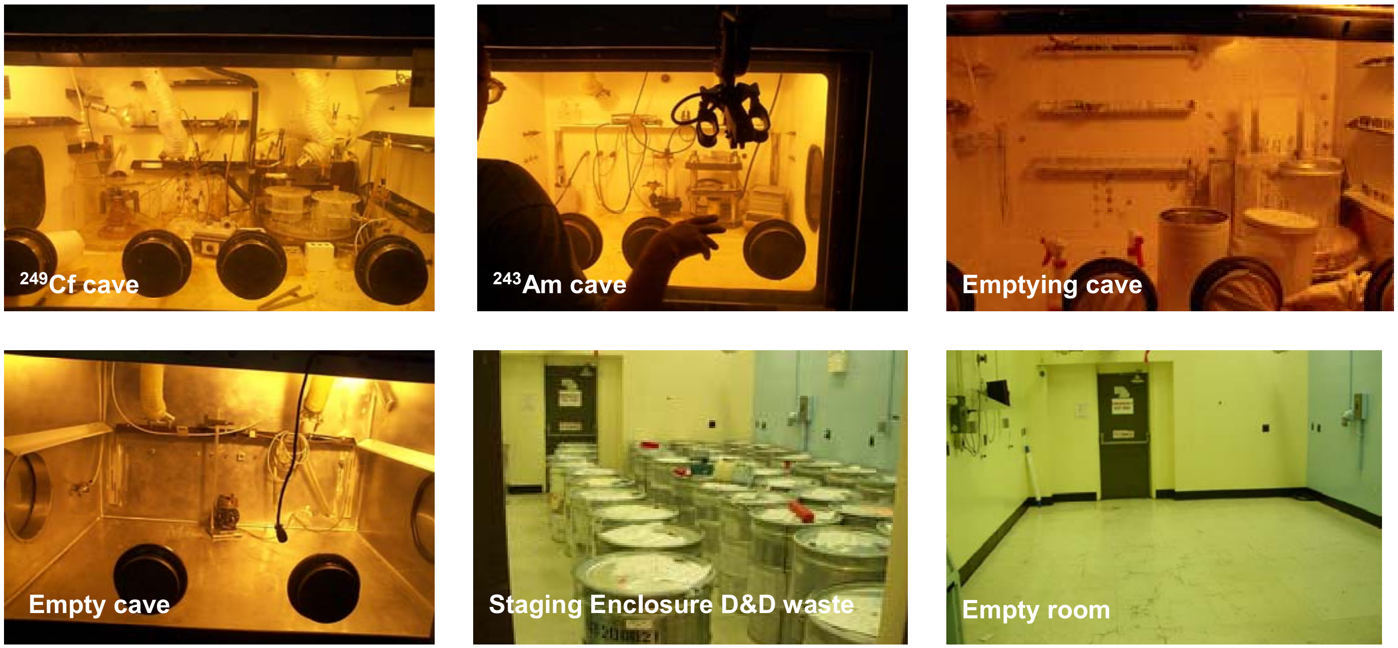


Figure 11. Examples of Legacy Equipment and Contamination

Enclosure D&D: Before and After

Heavy Element Facility B251



B251 Experimental Decontamination Results:

• Emptying removes large fraction of activity.

• One or two passes of Strip Coat removes bulk of loose activity. Scrubbing surface with acidic solution loosens remainder of surface activity. Material removed by another pass of strip coat.

• Additional passes of acid wash and Strip Coat remove less and less residual activity because residual material embedded under metal surface.

Figure 12. Before and After D&D